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ABSTRACT

A quantitative method developed at Stanford University that addresses programmatically the short- and long-term needs of the college physical plant is discussed. The approach allows the administrator to accurately assess funding resources for the maintenance program in conjunction with academic and construction programs. A special task force at the university established a conceptual framework based on predictable cycles for facility renewal and replacement. The task force identified five features that would affect the wearing out of the facility and system and the resulting replacement/renewal costs. These five features were: facility subsystems, facility type, subsystem life cycles, subsystem cost, and date of facility construction. These features were quantified by analyzing the existing physical plant and by researching available data. The objective was to forecast future renewal and replacment requirements. Using data that reflected actual conditions at the university, it was possible to model accurately Stanford's physical plant and to simulate the future renewal/replacement requirements. Each of the five features and resulting data set are discussed in detail in order to outline the methodology used for developing the data. (SW)

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APPA TECHNICAL PAPER

BEFORE THE ROOF CAVES IN: A PREDICTIVE MODEL FOR PHYSICAL PLANT RENEWAL

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APPA Technical Paper

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This paper will be printed in two parts. Part II will appear in the August issue.

The Problem

Higher education physical plants have expanded tremendously since the 1950s. Stanford University typifies this growth pattern with over 75 percent of its existing physical plant being constructed since 1955 to meet increasing academic demands.

A side effect of this rapid growth has been the creation of need for the future renewal and replacement of the physical plant. Often this need for plant renewal has not been fully accepted—especially true in recent periods of declining resources. This results in an erosion of university assets, since maintenance is usually the first budget item to be cut. If this erosion continues unchecked, many colleges and universities may soon be in a position where the roof is ready to cave in.

While the competent administrator does not knowingly allow these conditions to develop, he or she is frequently hindered by an incomplete understanding of the problem as a result of—

- difficulty in determining exactly what constitutes maintenance
- lack of an accepted quantitative method for evaluating and measuring maintenance needs
- lack of a consistent, long-range program that facilitates measuring results achieved vs. resources allocated.

These factors have made planning and budgeting for maintenance and renewal of the physical plant a difficult issue to address and resolve.

This paper presents a quantitative method developed at Stanford University, which addresses programmatically the short- and long-term needs of the physical plant. It allows the administrator to accurately assess the maintenance program in conjunction with academic and construction programs for funding resources.

Maintenance Programs and Methodologies

Methodologies for defining maintenance needs and programs are traditionally one of the three following types:

- *Straight line or historical funding*—the previous year's budget base is incremented by a certain percentage annually to compensate for identified changes such as inflation, additional personnel, etc.
- *Identification of needs based on physical survey*—a comprehensive facilities audit is conducted to identify and quantify all current maintenance deficiencies.
- *Formula funding*—annual maintenance needs are expressed in terms of cost per square foot, number of full-time employees per square foot, or a certain percentage of current physical plant value. This amount is to be reinvested annually.

Each of these methods has one or more major deficiencies. The straight line or historical funding does not match funding levels against identified needs. Additionally, the established base that is being incremented cannot be validated.

Physical surveys provide an accurate assessment of immediate needs but have no provisions for identifying long-term requirements, an essential ingredient to the planning and budgeting administration.

Formula budgeting is quantitatively based and can be used to project future needs. The formula method, however, only provides a general overview and cannot address the specific needs of a physical plant. This method's validity becomes even more questionable in light of the variety in age of facilities, their use, and construction materials.

In addition, both historical and formula funding assume that the plant renewal requirements will occur at a constant rate. This assumption seems inappropriate because of the identifiable life cycles of both facilities and their installed subsystems. These cycles are critical in determining the necessary, and varying, funding levels for future years.

Developing a Conceptual Framework

As part of the planning and budgeting process, administrators at Stanford University identified the need for a program that would accurately assess the future capital requirements necessary for renewal and replacement of the physical plant. The need for such a program is accentuated by the previously mentioned fact that over 75 percent of Stanford's existing physical plant had been constructed since 1955. As this large group of facilities enters its first major (and expensive) stage of deterioration, the need for funding of renewal and replacement becomes apparent.

A special task force established a framework within which the problems could be resolved. Task force members were drawn from various departments within the university that were concerned and interested in maintenance of the physical plant. The task force combined the financial, planning, and facilities departments and their respective viewpoints and expertise. This approach fostered a widespread understanding and acceptance of the results produced.

The basis of the conceptual framework is that predictable cycles exist for facility renewal and replacement. For example, the components or subsystems of a facility, such as plumbing, roofs, electrical, heating, ventilation, air conditioning systems, and installed equipment have identifiable life expectancies and will require replacement after predictable periods of time. These cycles will repeat themselves for as long as the facility serves its intended functions. Of great importance to the planning and budgeting administrator is the magnitude (constant dollars) of these replacement requirements and the time in the future they will occur. The replacement costs at these specified frequencies will approximate the annual reinvestment necessary to maintain the physical plant.

The task force developed the established framework by identifying the features that would have an impact on facility and system wear out and the resulting replacement/renewal costs. These features and underlying assumptions follow:

- *Facility subsystems*—quantity and type of installed subsystems (such as plumbing, electrical) within a facility will determine future requirements.
- *Facility type*—type of subsystems and associated costs vary with facility type.
- *Subsystem life cycles*—predictable life of a subsystem will determine when future requirements occur.
- *Subsystem cost*—unit replacement cost will determine the cost of future requirements.
- *Date of facility construction*—future time when requirements will occur is determined by the birthdate of the facility and subsystems.

Developing the Framework

To complete the established conceptual framework, the task force further defined and quantified the features or variables by analyzing the existing physical plant and by researching available data.

As the objective was to forecast future renewal and replacement requirements at Stanford, the values assigned to the variables reflected actual conditions at Stanford. This tailoring of the data provides a higher degree of accuracy in forecasting by being specifically representative of future requirements at Stanford. For example, subsystem cost is representative of the construction standards employed by Stanford. Subsystem life cycles similarly reflect the expected usable life experienced at Stanford.

Using data of this nature, it was possible to model accurately Stanford's physical plant and to simulate the future renewal/replacement requirements over time. This guided the development of the data to a format that would serve as input to a mathematical model. Each variable and resulting data set is discussed in detail in order to outline the methodology used for developing the data.

Again, the task force was able to draw on its engineering, construction, and maintenance expertise.

Facility Subsystems

Facility subsystems were identified as the individual parts/components or subsystems of a facility such as electrical systems, elevators, roofs, etc. The criteria established for identifying the subsystems follows:

- Each subsystem has an estimatable useful life.
- The total subsystem would constitute all parts of a facility that could eventually wear out or need replacement.
- Subsystem cost and performance data must be available.

The task force identified the subsystems based on this selection criteria (Figure 1).

Facility Type

Based on the assumption that subsystem types will vary with facility type, the task force analyzed the physical plant to determine the functional use of facilities in general. They determined functional use on a building-by-building basis by classifying each building as to its primary designated use. Although the task force considered multi-functional use of facilities, they decided not to let it influence their initial classification, which resulted in the identification of nine functional space types:

- Research laboratories
- Teaching laboratories
- Offices

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- Classrooms
- Libraries
- Athletics
- Residences
- Patient care
- Other (storage, etc.)

The task force then analyzed each of the identified space types to determine if it had subsystems that would rate it significantly different from the others. This analysis reduced the nine initial categories to five:

- Research/teaching laboratories
- Offices/classrooms/athletics/libraries
- Patient care
- Storage buildings and others with minimal usage
- Residences

The validity of this classification was then tested by selecting a representative sample from each facility category and analyzing the nature of the systems actually installed. While this analysis validated the above classification system, it also revealed the need to separately address facilities partially used as laboratories, because lab systems would significantly influence future renewal/replacement cost. Further analysis by percent of space used as laboratory vs. the system design of the facility revealed 30 percent to be the point at which functional use as a laboratory significantly influenced the subsystem design and resulting cost. Therefore, any facility that had at least 30 percent of its space designated as laboratory use was functionally classified as laboratory space.

Subsystem Life Cycles

Subsystem life cycles represent the useful life of the subsystem. The initial assumption applied to this variable was that the identified subsystem had been receiving and would continue to receive a normal level of maintenance. This restriction was made in order to keep it relatively simple and to use industry life cycle standards as a starting point. Initial life cycle data for each of the identified subsystems was compiled from various professional handbooks. This data represented a composite of engineering, maintenance, Internal Revenue System, and Treasury Department sources. Items having an average useful life assessed at one year or less were considered as an operational type of maintenance and were not included. The assessed life cycles were then analyzed in relation to historical experience at Stanford.

This comparison produced a sizable discrepancy in that the identified subsystems at Stanford have experienced a greater life span than the published data values indicate. The task force attributed this to two factors: the advantage in private business of high value and rapid depreciation, and the quality of construction standards at Stanford, which promote a longer useful life. To resolve this discrepancy, additional estimates of system lives were obtained from experts using the Delphi technique. With this technique, experts are independently polled using a series of interactive questionnaires. A separate panel of experts then analyzed all data sets.

Because of the variability of the types of subsystems, the conditions to which they were exposed and under which they were operated, there continued to be a large range in the life cycle estimates. The experts resolved this by assigning pessimistic, optimistic, and likely life cycle estimates to each subsystem. The panel also felt that some of the subsystems would not be subject to replacement under certain conditions. In this situation the useful life was designated as infinite. Figure 2 represents the final values assigned to each of the subsystems.

Figure 1: Components Included in Building Subsystems

Building Subsystem	Includes
Foundations and major vertical, floor, and roof structures	Excavation, piling, columns, load bearing and shear walls or bracing, floor slabs, beams and girders above grade
Roofing	Roofs, flashing, guttering and downspouts
Exterior cladding	Skylights, non-structural skin, insulation, external doors and windows*
Interior partitions	Non-load bearing walls, interior doors and windows, railing, sound insulation
Interior finishings	Floor coverings, plaster work, trim, drapes, paint, light fixtures
Elevators	Dumbwaiters, linen chutes, escalators
Plumbing	Hot and cold water, steam, gas, air vacuum lines
HVAC—moving	Fans, heating and cooling coils, motors, cooling towers
HVAC—static	Duct work, diffusers, registers
Electrical—moving	Switches, relays, circuit breakers
Electrical—static	Fuses, wiring
Fire protection	Automatic sprinklers
Special equipment and miscellaneous	Built-in appliances (ranges, ovens) and bookcases, cabinet work, folding room dividers, laboratory tables, special work areas, etc.

*Virtually all permanent academic facilities at Stanford are natural finish masonry construction. Hence, the external painting requirement was considered insignificant.

Subsystem Cost

The subsystem cost was defined as the unit replacement cost for the identified subsystems. Due to the realization that the functional use of a facility type may determine the subsystem replacement cost, a separate unit replacement cost for each subsystem in each facility was developed. For example, the mechanical systems in a research lab would be much more sophisticated and costly to replace than the mechanical system for classroom spaces.

Figure 2: Subsystem Life Estimates

Building Subsystem	Average Useful Life with Maintenance Program (Years) Pessimistic	Likely	Optimistic
Foundations and major vertical floor, and roof structures	—	—	—
Roofing	15	30	40
Exterior cladding	100	—	—
Interior partitions	75	100	—
Interior finishes	5	10	15
Elevators	20	40	75
Plumbing	30	50	80
HVAC—moving	10	15	25
HVAC—static	30	50	75
Electrical—moving	20	35	50
Electrical—static	30	50	75
Fire protection	60	80	100
Special equipment and miscellaneous	10	30	50

The task force initially derived the subsystem cost from various construction cost indexes. They compared these costs to an historical data base of Stanford construction cost data. This tailoring process made the data representative of expected cost at Stanford. The task force made a final adjustment by applying a multiplier factor of 1.3[1] to all data to reflect replacement cost as opposed to new construction cost. Figure 3 shows the derived unit cost of subsystems by facility type.

[1]A multiplier factor of 1.3 was applied to all cost to reflect replacement vs. new construction cost. As we are dealing with incremental replacement, it was necessary to adjust the Stanford new construction cost to account for the additional cost of demolition, removal, and reinstallation encountered during replacement. The 1.3 multiplier was derived by estimating the replacement cost for a cross section of each of the identified subsystems, and then comparing these costs to known construction costs.

This yielded a range of approximately 1.1 to 1.5 for the differential between new construction and replacement. Next, independent contractors who predominately perform renovation/repair work at Stanford were polled. Their consensus was that a factor of 1.3 should be used. Based on these two sets of data, a factor of 1.3 was used for all subsystems.

This paper was first published by the National Center for Higher Education Management Systems in Higher Education Planning and Budgeting: Ideas for the 80's.

Figure 3: Average Unit Renewal/Replacement Cost* by Building Subsystem

Building Subsystem	Patient Care	High Intensity Labs	Library, Office, Classroom, Low Intensity Labs, Athletics	Residential	Miscellaneous
Foundations and major vertical, floor and roof structures	$ 29.52	$ 34.65	$ 33.70	$ 19.10	$ 20.80
Roofing	2.30	3.20	3.50	4.10	2.85
Exterior cladding	19.68	9.55	10.40	11.50	8.55
Interior partitions	13.94	9.55	7.50	12.80	1.75
Interior finishes	16.40	7.70	6.20	9.80	3.65
Elevators	9.70	1.65	3.75	0.20	—0—
Plumbing	11.97	13.15	3.00	6.30	2.30
HVAC—moving	13.61	12.90	6.65	3.30	1.65
HVAC—static	13.61	12.90	6.65	3.30	1.65
Electrical—moving	15.38	14.70	7.40	4.55	4.60
Electrical—static	6.58	6.25	3.20	2.00	1.95
Fire protection	1.80	2.05	2.50	2.15	2.25
Special equipment and miscellaneous	9.51	14.95	5.60	8.60	0.60
Total replacement cost without structural shell	$134.48	$108.55	$ 66.35	$ 68.60	$ 31.80
Total with structural shell	$164.00	$143.20	$100.05	$ 87.70	$ 52.60
Estimated maximum error to "real" average total replacement costs	±20%	±30%	±20%	±20%	±20%

*All costs are measured in $/Ft² as of September 1980.

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